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(54) Title: CAVITATION ASSISTED SONOCHEMICAL HYDROGEN PRODUCTION SYSTEM

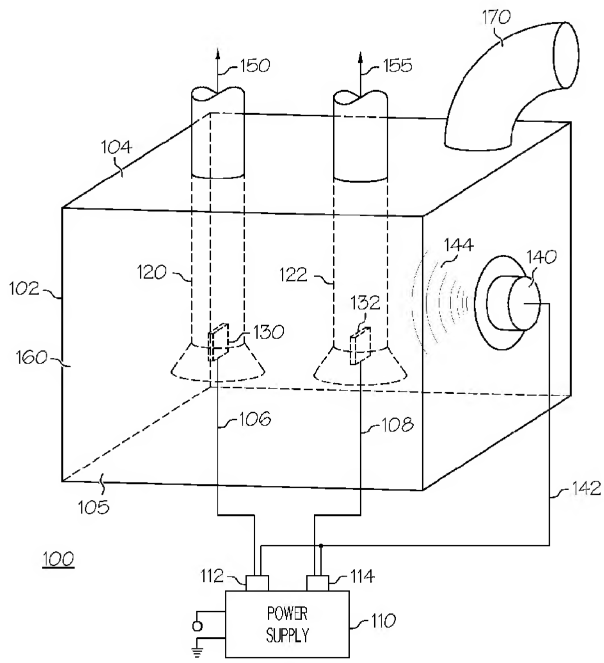

FIG. 1

(57) Abstract: A method and apparatus of producing hydrogen is disclosed comprising applying an electrical current to flow through an aqueous solution. Cavitation is generated within the aqueous solution, where the cavitation lowers an amount of energy required to break chemical bonds of said aqueous solution.

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CAVITATION ASSISTED SONOCHEMICAL HYDROGEN PRODUCTION SYSTEM

Field of the Invention

[0001] The present invention generally relates to efficient generation of hydrogen and more specifically to in-situ hydrogen generation.

Background of the Invention

[0002] Water is composed of two parts hydrogen and one part oxygen by mass or volume. Decomposed by any means, two moles of water will produce one mole of oxygen gas (0_2) and two moles of hydrogen gas (H_2) at a given input of energy E1. When combined together through any means, hydrogen and oxygen react to form water, releasing a given output of energy E2. By all known principles of physics and chemistry, E1 > E2 and thus by thermodynamics the process is not favored in direct action. For hydrogen to be useful as an energy source and economical to use, a means must be created to either reduce the dissociation energy of water, or provide energy in some other fashion in the process, for example with catalytic enhancement, or all the above.

[0003] Hydrogen can be manufactured by a variety of means (including, but not limited to chemical, electrical, thermal, radiolysis, etc.) from a variety of chemical substances (including, but not limited to, water, hydrocarbons, plants, rocks, etc.). In the present invention water is used as the hydrogen source and a catalytic combination of electrolysis and cavitation is used to generate the hydrogen. The method of cavitation may be by a variety of means (acoustical, hydrodynamic inertial, non-inertial, mechanical, electromagnetic, etc.), or any combination thereof.

[0004] Hydrogen, being the most abundant element on earth as well as in the Universe, holds particular promise as a fuel source, both on earth as well as in space. Hydrogen can power homes and factories, transportation modes (planes, trains, and vehicles). Thus, hydrogen can serve to eliminate carbon fuels completely in the electrical cycle, thus bringing about a net subtraction by the contribution of anthropomorphic processes to terrestrial climate change. There are four significant "hurdles" cited by numerous reviews to the use of hydrogen. Each is noted as follows.

[0005] 1. Production-How to produce massive amounts of hydrogen in an efficient, safe, environmentally ‘friendly’ fashion.

[0006] 2. Storage-How to store the low density, flammable gas.

[0007] 3. Distribution-Hydrogen, being difficult to store, is thus difficult to transport.

[0008] 4. Use-How can hydrogen be used is a bigger hurdle in light of the prior two items.

[0009] Accordingly what is needed is a method and system to overcome the problems encountered in the prior art and to provide an economical method and apparatus to produce hydrogen.

Summary of the Invention

[0010] A method and an apparatus to generate hydrogen gas as H_2 from a hydrogen containing liquid such as water. In one embodiment, the structure is a electrolytic cell configured with catalytic enhancements to maximize the volume and mass of hydrogen produced, and minimize the energy input, thus minimizing cost of operation. This device is particularly configured to enhance catalytically the decomposition of water and the formation of hydrogen gas by: 1) the container apparatus configuration of electric and magnetic fields; 2) the use of sonochemistry and cavitation; and 3) the use of applicable solutes and solvents in the device that change the pH, ionic state, and the chemical potential of the device solution.

[0011] The cavitation may be generated by a variety of means including but not limited to, acoustic energy, hydrodynamic (inertial, non-inertial), mechanical, electromagnetic energy, etc., or any combination thereof.

[0012] There are four significant “hurdles” cited by numerous reviews to the use of hydrogen. Each is noted as follows.

[0013] 1. Production-How to produce massive amounts of hydrogen in an efficient, safe, environmentally ‘friendly’ fashion. This patent is capable of producing hydrogen from water, and by any fashion in its recombination with oxygen to re-from water, producing no pollution whatsoever and returning water back to its original form.

[0014] 2. Storage-How to store the low density, flammable gas. This patent eliminates the need for storage, by creating a scalable process to generate hydrogen from water in-situ wherever it is needed. It thus eliminates the need for dangerous, costly, and hazardous storage and transport issues.

[0015] 3. Distribution-Hydrogen, being difficult to store, is thus difficult to transport. Again, this patent eliminates the need for storage and thus transport, by creating a scalable process to generate hydrogen from water in-situ wherever it is needed. There is no need for dangerous, costly, and hazardous storage, distribution, and transport issues.

[0016] 4. Use-How can hydrogen be used is a bigger hurdle in light of the prior two items. With the elimination of those two items, the relative cost of the use of fuel cells becomes economical even to the middle class. Without the need for refueling, or by minimizing the need for refueling, the ability to use fuel cells will become ubiquitous to modern life.

[0017] A method and apparatus of producing hydrogen is disclosed comprising applying an electrical current to flow through an aqueous solution. Cavitation is generated within the aqueous solution, where the cavitation lowers an amount of energy required to break chemical bonds of said aqueous solution.

[0018] The foregoing and other features and advantages of the present invention will be apparent from the following more particular description of the preferred embodiments of the invention, as illustrated in the accompanying drawings.

Brief Description of the Drawings

[0019] The subject matter, which is regarded as the invention, is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features, and advantages of the invention will be apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

[0020] FIG. 1 is a diagram of a first embodiment of a hydrogen production system according to the present invention.

[0021] FIG. 2 is a diagram of a second embodiment of a hydrogen production system according to the present invention

[0022] FIG. 3 is a diagram of a conical funnel member of FIG. 2.

[0023] FIG. 4 is a diagram of a third embodiment of a hydrogen production system according to the present invention

[0024] FIG. 5 is a diagram of a first cavitation subsystem according to the present invention.

[0025] FIG. 6 is a diagram of a second cavitation subsystem according to the present invention.

[0026] FIG. 7 is a diagram of the major factors affecting hydrogen production.

Description Of The Preferred Embodiments

[0027] It should be understood that these embodiments are only examples of the many advantageous uses of the innovative teachings herein. In general, statements made in the specification of the present application do not necessarily limit any of the various claimed inventions. Moreover, some statements may apply to some inventive features but not to others. In general, unless otherwise indicated, singular elements may be in the plural and vice versa with no loss of generality.

[0028] In this patent the following definitions apply when these words are used:

[0029] Cavitation- Cavitation is the phenomenon of formation (irregardless of mechanism) of vapor bubbles in a fluid, in the region where the pressure of the fluid falls below its vapor pressure. Cavitation can be divided into two classes of behavior: inertial (or transient) cavitation, and non-inertial cavitation. Inertial cavitation is the process where a void or bubble in a liquid rapidly collapses, producing a shock wave. Non-inertial cavitation is the process where a bubble in a fluid is forced to oscillate in size or shape due to some form of energy (such as acoustic fields) input.

[0030] Acoustic Energy- For the purposes of this patent, acoustic energy refers to all frequencies, as well as any radiation of any frequency or wavelength in the electromagnetic spectrum. Also for the purposes of this patent, acoustic energy, as well as any radiation of any

frequency or wavelength in the electromagnetic spectrum, may be employed as a single frequency (wavelength) or any frequency combination thereof (as a discrete sum, difference, harmonics, sub-harmonics, overtones, series, etc.).

[0031] First Embodiment of Hydrogen Production System

[0032] FIG. 1 is a cross sectional side view of the hydrogen production system 100 according to the present invention. Hydrogen production system 100 consists of a container apparatus 102 in the fashion of an electrolytic cell capable of storing a volume of a solution 160. Solution 160 is comprised of a solvent and solute. The solvent is preferably water or another aqueous solution containing hydrogen. The solute is a chemical compound capable of carrying an electrical charge i.e. an electrolyte. The sides of container apparatus 102 are preferably non-electrically conductive. Two electrically-conductive pieces 130 and 132 are held above the bottom member 105 of container apparatus 120 by supporting members 106 and 108, respectively. The electrically-conductive piece 130 is connected to the negative terminal 112 of power supply 110. Thus, the electrically-conductive piece 130 is a cathode. Likewise, the electrically conductive piece 132 is connected to the positive terminal 114 of power supply 110. Thus, the electrically-conductive piece 132 is an anode. A hollow, cylindrical tube 120 is connected to and passes though top member 104 of container apparatus 102. The bottom of tube 120 is flared outward and positioned so that the bottom of tube 120 is below the bottom of cathode 130 but not touching bottom member 105 of container apparatus 102. Likewise, a hollow, cylindrical tube 122 is connected to and passes through top member 104 of container apparatus 102. The bottom of tube 122 is flared outward and positioned so that the bottom of tube 122 is below the bottom of anode 132 but not touching bottom member 105 of container apparatus 102. Finally, a transducer 140 is connected to one side of container apparatus 102. Wires 142 connect transducer 140 to power supply 110.

[0033] As previously mentioned, power supply 110 causes cathode 130 to be negatively charged and anode 132 to be positively charged. As a result, an electrical current is created between cathode 130 and anode 132. The electrical current electrolyzes solution 160 and causes hydrogen to form around cathode 130 and oxygen to form around anode 132. Tube 120 funnels the hydrogen out of container apparatus 102 for use further use (shown by arrow 150), such as to provide fuel for hydrogen fuel cells or to directly power an engine. Likewise tube 122 funnels the oxygen out of container apparatus 102 (shown by arrow 155). As

solution 160 is electrolyzed and the constituent gases are removed from the system 100, additional solution can be added through an inlet 170.

[0034] Transducer 140 produces acoustic energy waves 144 which transmit through and cause cavitation in solution 160. This cavitation decreases the energy required to break the chemical bonds of solution 160. As a result, in the presence of cavitation, a greater amount of hydrogen is produced at cathode 130 at a given voltage than in the absence of cavitation. Alternatively, in the presence of cavitation, the same amount of hydrogen is produced at cathode 130 at a lower voltage than in the absence of cavitation.

[0035] Hydrogen production system 100 is designed to be portable. In one embodiment, hydrogen production system 100 is sized approximately 8" in length by 8" in width by 8" in height so that it can fit as an engine component in a vehicle. However, it is clear to one skilled in the art that hydrogen production system 100 and its components can be scaled larger or smaller without affecting the spirit and scope of the present invention. Likewise, it is clear to one skilled in the art that hydrogen production system 100 and its components can take on many different shapes without affecting the spirit and scope of the present invention. FIG. 1 shows one embodiment of the present invention where container apparatus 102 is shaped to allow maximum transmittal of sound waves 144 though solution 160. Finally, it is clear to one skilled in the art that any number of transducers 140 may be placed at various locations on container apparatus 102 and used to produce acoustic energy waves 144 in order to maximize the creation of cavitation within solution 160.

[0036] <u>Second Embodiment of Hydrogen Production System</u>

[0037] FIG. 2 is a cross sectional side view of another embodiment, referred to as hydrogen production system 200, of the present invention. Hydrogen production system 200 consists of a container apparatus 202 in the fashion of an electrolytic cell capable of storing a solution 160. The sides of container apparatus 102 are preferably non-electrically conductive. A hollow, cylindrical, electrically conductive piece 230 is held above the bottom member 207 of container apparatus 202 by supporting members 232. A second electrically conductive member 234 is held above the bottom member 207 of container apparatus 202 by supporting member 205. Electrically conductive piece 230 is connected to the positive terminal 214 of power supply 210. Thus, electrically conductive piece 230 is an anode. Likewise, electrically conductive piece 234 is connected to the negative terminal 212 of power supply 210. Thus,

electrically conductive piece 234 is a cathode. A hollow, cylindrical tube 220 is connected to and passes through top member 206 of container apparatus 202. The bottom of tube 220 is flared outward and positioned so that some portion of cathode 234 is within the tube 220. Finally, a transducer 240 is connected to one side of container apparatus 202. Wires 242 connect transducer 240 to power supply 210.

[0038] Power supply 210 causes cathode 234 to be negatively charged and anode 230 to be positively charged. As a result, an electrical current is created between cathode 234 and anode 230. The cylindrical shape of anode 230 and the position of cathode 234 along the axis of anode 230 takes advantage of the electrical field produced by cathode 234 and anode 230 and helps to maximize the flow of electricity between cathode 234 and anode 230.

[0039] As previously described, the electrical current flowing between cathode 234 and anode 230 electrolyzes solution 160 and causes hydrogen to form around cathode 234 and oxygen to form around anode 230. Tube 250 funnels the hydrogen out of container apparatus 202 for further use (shown by arrow 250). Referring to FIG. 3, a conical piece 310 is placed on top of anode 230. Conical piece 310 funnels oxygen out of container apparatus 202 (shown by arrow 340). Referring back to FIG. 2, as solution 160 is electrolyzed and the constituent gases are removed from the system 100, additional solution can be added through an inlet 280.

[0040] Hydrogen production system 200 is the same as hydrogen production system 100 in that transducer 240 produces sound waves 244 which transmit through and cause cavitation in solution 160. This cavitation decreases the energy required to break the chemical bonds of solution 160 via electrolysis. As a result, in the presence of cavitation, a greater amount of hydrogen is produced at cathode 234 at a given voltage than in the absence of cavitation. Alternatively, in the presence of cavitation, the same amount of hydrogen is produced at cathode 234 at a lower voltage than in the absence of cavitation.

[0041] Hydrogen production system 200 is designed to be portable. In one embodiment, hydrogen production system 200 is sized approximately 8” in length by 8” in width by 8” in height so that it can fit as an engine component in a vehicle. However, it is clear to one skilled in the art that hydrogen production system 200 and its components can be scaled larger or smaller without affecting the spirit and scope of the present invention. Likewise, it is clear to one skilled in the art that hydrogen production system 200 and its components can take on

many different shapes without affecting the spirit and scope of the present invention. FIG. 2 shows one embodiment of the present invention where container apparatus 202 is shaped to allow maximum transmittal of acoustic energy waves 244 though solution 160. Finally, it is clear to one skilled in the art that numerous transducers 240 may be placed at various locations on container apparatus 202 and used to produce acoustic energy waves 244 in order to maximize the creation of cavitation within solution 160.

[0042] Third Embodiment of Hydrogen Production System

[0043] FIG. 4 is a cross sectional side view of another embodiment, referred to as hydrogen production system 400, of the present invention. Hydrogen production system 400 consists of a cylindrically-shaped container apparatus 402 in the fashion of an electrolytic cell capable of storing a solution 160. Container apparatus 402 has an electrically conductive inner wall 403 and a non-electrically conductive outer wall 470. An electrically conducive piece 430 is held above the bottom member 407 of container apparatus 402 by supporting member 405. Electrically conductive inner wall 403 is connected to the positive terminal 414 of power supply 410. Thus, conductive inner wall 403 is an anode. Electrically conductive piece 430 is connected to the negative terminal 412 of power supply 410. Thus, electrically conductive piece 430 is a cathode. A hollow, cylindrical tube 420 is connected to and passes through the top member 480 of container apparatus 402. The bottom of tube 420 is flared outward and position so that some portion of cathode 430 is within tube 420. Finally, a transducer 440 is connected to bottom member 407 of container apparatus 402. Wires 444 connect transducer 440 to power supply 410.

[0044] Power supply 410 causes cathode 430 to be negatively charged and anode 403 to be positively charged. As a result, an electrical current is created between cathode 430 and anode 403. The cylindrical shape of anode 403 and the position of cathode 430 along the axis of anode 403 takes advantage of the electrical field produced by cathode 430 and anode 403 and helps to maximize the flow of electricity between cathode 430 and anode 403.

[0045] As previously described, the electrical current flowing between cathode 430 and anode 403 electrolyzes solution 160 and causes hydrogen to form around cathode 430 and oxygen to form around anode 403. Tube 420 funnels the hydrogen out of container apparatus 402 for further use (shown by arrow 450). Conically-shaped top member 480 of container apparatus 402 funnels oxygen out of container apparatus 402 (shown by arrow 455). As

solution 160 is electrolyzed and the constituent gases are removed from the system 400, additional solution can be added through an inlet 490.

[0046] Hydrogen production system 400 is the same as hydrogen production systems 100 and 200 in that transducer 440 produces acoustic energy waves 442 which transmit through and cause cavitation in solution 160. This cavitation decreases the energy required to break the chemical bonds of solution 160 via electrolysis. As a result, in the presence of cavitation, a greater amount of hydrogen is produced at cathode 430 at a given voltage than in the absence of cavitation. Alternatively, in the presence of cavitation, the same amount of hydrogen is produced at cathode 430 at a lower voltage than in the absence of cavitation.

[0047] Hydrogen production system 400 is designed to be portable. In one embodiment, hydrogen production system 400 is sized approximately 8" in length by 8" in width by 8" in height so that it can fit as an engine component in a vehicle. However, it is clear to one skilled in the art that hydrogen production system 400 and its components can be scaled larger or smaller without affecting the spirit and scope of the present invention. Likewise, it is clear to one skilled in the art that hydrogen production system 400 and its components can take on many different shapes without affecting the spirit and scope of the present invention. Finally, it is clear to one skilled in the art that any number of transducers 440 may be placed on container apparatus 402 and used to produce sound waves 442 in order to maximize the creation of cavitation within solution 160.

[0048] Throughout the descriptions of hydrogen production systems 100, 200, and 400, a cylindrical tube, tube 120, 250, and 420, is used to capture hydrogen formed around the cathode and direct the hydrogen out of the systems. It will be clear to one skilled in the art that tubes 120, 250, and 450 can be replaced by any means to capture and direct the hydrogen. Such means include, but are not limited to, tubes and similarly shaped conduits, membrane filtering, diffusive evaporation, differential pressures, and channeling solution flow.

[0049] <u>Embodiments of Cavitation Sub-System</u>

[0050] Throughout the descriptions of hydrogen production systems 100, 200, and 400, transducers 140, 240, and 440 are used to produce acoustic energy waves 144, 244, and 442 which cause cavitation within solution 160. It will be clear to one skilled in the art that transducers 140, 240, and 440 can be replaced by any means for generating cavitation. Such

means for creating cavitation include, but are not limited to, acoustic means, mechanical means, hydrodynamic means, electromagnetic means, and ionizing radiation means.

[0051] Figures 1, 2 and 4 show embodiments of the present invention where the cavitation is produced by a specific acoustic means, namely, by using a transducer to pass acoustic energy waves through solution 160. However, other acoustic means can be used to produce the cavitation. It will be understood by one having skill in the art that such acoustic means includes, but is not limited to, transducers, microphones, and speakers.

[0052] An example of a mechanical means to cause cavitation within hydrogen production systems 100, 200, and 400 includes, but is not limited to, a propeller system contained within container apparatus 102, 202, and 402, which causes cavitation as the propeller spins on its axis. FIG. 5 shows a cross sectional view of such a propeller system. As shown, propeller blades 520 spin about the axis of propeller system 510 causing cavitation to be produced in solution 160. Propeller system 510 may be powered by power source 110, 210, or 410. It will be understood by one having skill in the art that other mechanical means can be used to produce the cavitation. Such mechanical means include, but are not limited to, a propeller system, pistons, shock tubes, and light gas guns.

[0053] An example of a hydrodynamic means to cause cavitation within hydrogen production systems 100, 200, and 400 includes, but is not limited to, the injection of a compressed gas, for example, compressed air, into container apparatus 102, 202, and 402 to cause cavitation. FIG. 6 shows a cross sectional view of such a compressed gas injection system. As shown, compressed gas injection system 610 is affixed to container apparatus 102, 202, or 402. Compressed gas travels (indicated by arrows 640) from a compressor (not shown) through tube 630 to compressed gas injection system 610. The compressed gas flows through tubes 620 and is introduced into solution 160 as bubbles, i.e. cavitation. In one embodiment, compressed gas injection system 610 may be separated from solution 160 by a porous membrane that permits the transfer of the compressed gas through the membrane while preventing solution 160 from entering compressed air system 610. An example of such a membrane is Gore-Tex. It will be understood by those having skill in the art that other hydrodynamic means can be used to produce the cavitation. Such hydrodynamic means include, but are not limited to, a compressed gas injector system and any device capable of

transferring momentum into solution 160 without transferring mass into solution 160, for example, a shock plate or paint shaker.

[0054] An example of an electromagnetic means to cause cavitation within the hydrogen production systems 100, 200, and 400 includes, but is not limited to, a laser beam directed to pass into solution 160 so as to produce a shock wave that causes cavitation within solution 160. It will be understood by those having skill in the art that other electromagnetic means can be used to produce cavitation. Such electromagnetic means include, but are not limited to, a laser beam, x-rays, gamma rays, high speed electrons, electric arc, magnetic compression, plasma generation, and electromagnetic radiation arising from any type of electron or proton reaction.

[0055] Finally, an example of an ionizing radiation means to cause cavitation within the hydrogen production systems 100, 200, and 400 includes, but is not limited to, passing high energy protons into solution 160 where cavitation is formed around the protons. Generally, ionizing radiation is any radiation that is capable of removing an electron from a chemical bond. Therefore, it will be understood by those having skill in the art that such ionizing radiation means include, but are not limited to, all electromagnetic radiation greater in energy than ultraviolet radiation and high energy particles such as photons, protons, neutrons, and charged and uncharged nuclei.

[0056] Throughout the descriptions of hydrogen production systems 100, 200, and 400, as well as the examples of the various means of causing cavitation, cavitation is said to occur within solution 160. It will be understood by those having skill in the art that causing cavitation "within" solution 160 means causing cavitation within the electrolytic zone.

[0057] FIG. 7 is a diagram of the major factors affecting the production of hydrogen according to the present invention. Solution factors 710 are the major factors affecting solution 160. These solutions factors include a solvent and solute. As previously described, the solvent is water or another aqueous solution containing hydrogen. The solute is a chemical compound, such as acid (such as HI or HCl), base (NaOH), or salt (such as KI or NaI), and is held at a particular density per volume of solvent in order to maximize the electrical conductivity of the solution. The solution has a particular pH, and it is held at a particular temperature and pressure, whether in hydrogen production system 100, 200, or 400,

to minimize the energy required to break the chemical bonds of the solvent. Finally, the solution has a particular ionic and covalent state (chemical potential).

[0058] Power factors 720 are the major factors affecting the delivery of power to cathodes 130, 234, and 430, and anodes 132, 230, and 403. It will be readily apparent to one skilled in the art that the power factors 720 include voltage applied, current applied, and total power applied. Additionally, although hydrogen production systems 100, 200, and 400 have been shown with a single cathode and single anode, it is apparent to one skilled in the art that the number of voltage/current applications points can be increased without affecting the spirit and scope of the present invention. Likewise it is apparent to one skilled in the art that the sizes and shapes of cathodes 130, 234, and 430 and anodes 132, 230, and 403 can change without affecting the spirit and scope of the present invention. Finally, it is apparent to one skilled in the art that power supplies 110, 210, and 410 can be any power producing device, such as a battery, solar panel, or fuel cell.

[0059] Material Composition factors 730 are the major factors affecting the materials of the hydrogen production systems 100, 200, and 400. The materials comprising cathodes 130, 234, and 430, and anodes 132, 230, and 403 are selected to maximize electrical conductivity. Such materials include, but are not limited to, metals such as copper, platinum, and high order non-linear crystals including, but not limited to, lithium niobate and lithium tantalate.

[0060] The catalytic factors 740 employed to enhance and catalyze the production of hydrogen are the major factors affecting the energy balance within solution 160. The non-energy input catalytic factors lowering the necessary electrolytic input energy ΔE_1 to ΔE_2 include but are not limited to: (1) process temperature (as a function of ΔE_{cav}, ΔE_2, partial molar concentrations of species), (2) container properties (composition, shape), (3) solution properties (solute/solvent composition [species, concentrations, etc.], pH, chemical potential, pressure, catalytic agents added [supported catalysts, gases such as noble gases, etc.]), (4) electrode properties (composition [elemental, isotopic, chemical], shape, microsurface [crystal planes, etc.], macrosurface [holes, edges, etc.], and (5) structure of applied electromagnetic field [energized, unenergized]).

[0061] Referring to Table 1, a set of equations is set forth showing that even in the presence of cavitation, the energy required to perform the electrolysis of solution 160 to produce hydrogen is greater than the energy that is produced when that hydrogen is recombined with

oxygen. Thus, it is apparent to one skilled in the art that the teachings described herein are not directed to a perpetual energy device. Rather, because of the net energy loss that results from the electrolysis of solution 160, energy is introduced into systems 100, 200, and 400 as represented by power supplies 110, 210, and 410 to drive the electrolysis and catalytic processes.

1	Electrolysis (decomposition) of water requires energy *input*: E_{dec} $2\,H_2O\,(l) \rightarrow 2\,H_2\,(g) + O_2\,(g) \quad E_{dec}$ $E_{dec} / 2 = \quad E_1$ ---> energy consumed per mole H_2O or H_2 .
2	Formation of water requires energy *output*: E_{form} $2\,H_2\,(g) + O_2\,(g) \rightarrow 2\,H_2O\,(l) \quad E_{form}$ $E_{form} / 2 = \quad E_2 \rightarrow$ energy released per mole H_2O or or H_2 .
3	By the First Law of Thermodynamics, electrolysis is not fully reversible since the heat and entropy losses cannot be fully accounted for. Thus, we have the result: $E_1 > \quad E_2$ *always.* As a result, the process of electrolysis/water reformation, as well as the process described herein cannot be termed a “Perpetual Motion (or Energy) Machine” of any kind.
4	The thermodynamic efficiency relation $= \quad E_2 / \quad E_1$ X 100% gives a guide to the relative efficiency of the electrolysis/water reformation process. An eventual efficiency of 80% or more is possible.
5	E_1 (energy consumed per mole H_2O or H_2 to decompose water to H_2 gas) may be represented in the present invention by the quantity E_3 , which is: $E_3 = \quad E_{electrolysis} + \quad E_{cavitation} + \quad E_{other}$ where the electrolysis term represents only the electrical energy input from the electrodes as electrolysis, the cavitation term represents only the electrical energy input from acoustical energy (or any means) to cause or sustain cavitation, and the

	'other' term represents any energy input for heating, cooling, stirring, or measurement. Here energy is represented as the total energy (power) input as the function of current and voltage by Ohm's Law.
6	In the absence of catalytic factors 740, $E_{electrolysis} \sim E_1$. However, for the process described herein to be valid, $E_{electrolysis}$ must be less than E_1: $E_1 > E_{electrolysis}$ since the process described herein is a catalytic process which lowers the necessary energy to form hydrogen gas. Thus, the overall equation is: $[\ E_3 = E_{electrolysis} + E_{cavitation} + E_{other}\ ] \leq E_2$ which requires the value E_3 to approach E_2. Since $E_1 > E_2$ always, the equation $E_1 > E_3$ is valid.
7	Generally, there are two kinds of catalytic factors: non-energy input catalytic factors which are based on no energy input (e.g. electrode materials, configurations, etc.); and energy input catalytic factors which are based on energy input (e.g. cavitation, heating, cooling, stirring, etc). Examples of both kinds of catalytic factors are set forth in catalytic factors 740.

Table 1.

[0062] Referring back to FIG. 7, the energy input factors 750 lowering the electrolytic input energy ΔE_1 to ΔE_2 include, but are not limited to: (1) ΔE_{other} (energy necessary for the temperature control and measurement, mechanical, stirring, etc.), and (2) ΔE_{cav} (cavitator properties [size, shape, composition], configuration [number, density per unit area/volume, etc.], power input [f (V, I)], acoustic frequency spectrum input, electromagnetic frequency spectrum input). As described above, a cavitator can be any device capable of causing cavitation.

[0063] It has been advantageously shown that the following factors in one embodiment, hydrogen production system 400, greatly increase hydrogen production in the present invention: (1) the use of a specific acoustical spectrum to maximize cavitation in solution 160; (2) the use of sodium or potassium iodide salt in solution 160 to maximize the conductivity and chemical potential of solution 160; (3) the dissolution of an effective amount of noble gas into solution 160, such that the noble gas is completely dissolved in the solution, to electromagnetically enhance the production of cavitation thus maximizing the generation of hydrogen gas – in the present embodiment, the noble gas is preferably argon and an effective

amount of noble gas to be completely dissolved in solution 160 is up to five percent (5%) at Standard Temperature and Pressure; (4) the shape and configuration of the electrodes, which for hydrogen production system 400 comprise the electrically conductive inner wall 403 and electrically conductive inner piece 430, to (i) maximize the mechanical separation of the hydrogen and oxygen gas products and (ii) maximize the electrolysis electric field by use of the cylindrical electrode configuration (which maximizes the electric field by a multiplicative ratio of the inner and outer radii); and (5) the shape of the container, for example, hydrogen production system 400 comprises an electrically conductive inner wall 403 contained within an non-electrically conductive outer wall 470 so as to electrically isolate the function of the hydrogen production system 400 from the outside world.

[0064] Likewise, although it is clear to one skilled in the art that the solution 160 may be exposed to any temperature and/or pressure and that solution 160 may be contained within either a sealed or unsealed container, it has been advantageously shown for one embodiment, hydrogen system 400, that the hydrogen production using the teachings described herein is preferably performed in a sealed, but not pressurized, container at approximately Standard Temperature and Pressure (STP).

[0065] Additionally, it is self evident that the teachings and embodiments set forth herein are focused on minimizing the amount of input energy while maximizing the output of hydrogen gas. The most important factor affecting the total input energy is electrolysis voltage. Thus, it is self evident that requiring less input voltage for the same given amount (or greater) of hydrogen gas generated will result in requiring less input energy, thus, less input power. As a result of requiring less input power, <u>the input-output thermodynamic difference is minimized</u> and as a result a larger fraction of input power can be generated by energy sources such as solar cells, recharged batteries, etc., thus maximizing overall efficiency and quantity of hydrogen generated.

[0066] Although a specific embodiment of the invention has been disclosed, it will be understood by those having skill in the art that changes can be made to this specific embodiment without departing from the spirit and scope of the invention. Likewise, it will be understood by those having skill in the art that the teachings herein can be scaled in size to increase or decrease hydrogen production without affecting the scope and spirit of the present invention. The scope of the invention is not to be restricted, therefore, to the specific

embodiment, and it is intended that the appended claims cover any and all such applications, modifications, and embodiments within the scope of the present invention.

[0067] What is claimed is:

CLAIMS

1. A method of producing hydrogen comprising:

applying an electrical current to flow through a solution containing hydrogen; and

generating cavitation within the solution, where the cavitation lowers an amount of energy required to break chemical bonds of the solution.

2. The method according to claim 1, wherein generating cavitation within the solution further comprises causing acoustic energy to pass through the solution, the acoustic energy producing cavitation within the solution.

3. The method according to claim 1, wherein the step of generating cavitation is performed using any electromagnetic means.

4 The method according to claim 1, wherein the step of generating cavitation is performed using a transducer.

5. The method according to claim 1, wherein the step of generating cavitation is performed using a propeller system.

6. The method according to claim 1, wherein, the step of generating cavitation is performed using compressed gas.

7. The method according to claim 1, wherein the step of generating cavitation is performed by radiation.

8. The method according to claim 1, wherein the solution contains an effective amount of noble gas to be completely dissolved in the solution.

9. The method according to claim 1, wherein the solution comprises a solvent and a solute and the solute further comprises at least one of an iodide salt or iodate salt.

10. The method according to claim 1, wherein the solution comprises a solvent and a solute and the solution contains an effective amount of noble gas to be completely dissolved in the solution and the solute further comprises at least one of an iodide salt or iodate salt.

11. An apparatus for producing hydrogen comprising:

a container;

a solution containing hydrogen contained within the container;

a first electrically conductive piece, where said first electrically conductive piece is in contact with the solution;

a second electrically conductive piece, where said second electrically conductive piece is in contact with the solution;

a power supply having a negative output and a positive output, where the negative output is connected to the first electrically conductive piece and the positive output is connected to the second electrically conductive piece thereby causing an electric current to flow through the solution between the first electrically conductive piece and second electrically conductive piece;

means for causing cavitation in the solution; and

means for capturing hydrogen formed around the negative electrical piece.

12. The apparatus of claim 11, wherein the means for causing cavitation in the solution comprises a transducer capable of transmitting acoustic energy waves through the solution.

13. The apparatus of claim 11, wherein the means for causing cavitation in the solution comprises a propeller system.

14. The apparatus of claim 11, wherein the means for causing cavitation in the solution comprises a compressed gas injector system capable of injecting compressed air bubbles into the solution.

15. The apparatus of claim 11, wherein the solution contains an effective amount of noble gas to be completely dissolved in the solution.

16. The apparatus of claim 11, wherein the solution comprises a solvent and a solute and the solute further comprises at least one of an iodide salt or iodate salt.

17. The apparatus of claim 11, wherein the solution comprises a solvent and a solute and the solvent contains an effective amount of noble gas to be completely dissolved in the solution and the solute further comprises at least one of an iodide salt or iodate salt.

18. An apparatus for producing hydrogen comprising:

a container;

a solution containing hydrogen contained within the container;

a first electrically conductive piece, where said first electrically conductive piece is adjacent to the solution;

a second electrically conductive piece, where said second electrically conductive piece is adjacent to the solution;

a power supply having a negative output and positive output, where the negative output is connected to the first electrically conductive piece and the positive output is connected to the second electrically conductive piece thereby causing an electric current to flow through the solution between the first electrically conductive piece and second electrically conductive piece;

a cavitation generator using at least one of a transducer, a propeller system, a compressed air injector system; a laser, or a beam of ionizing radiation, and

a hydrogen capturing device using at least one of a tube, a membrane filter, diffusive evaporation, differential pressure, or channeling solution flow.

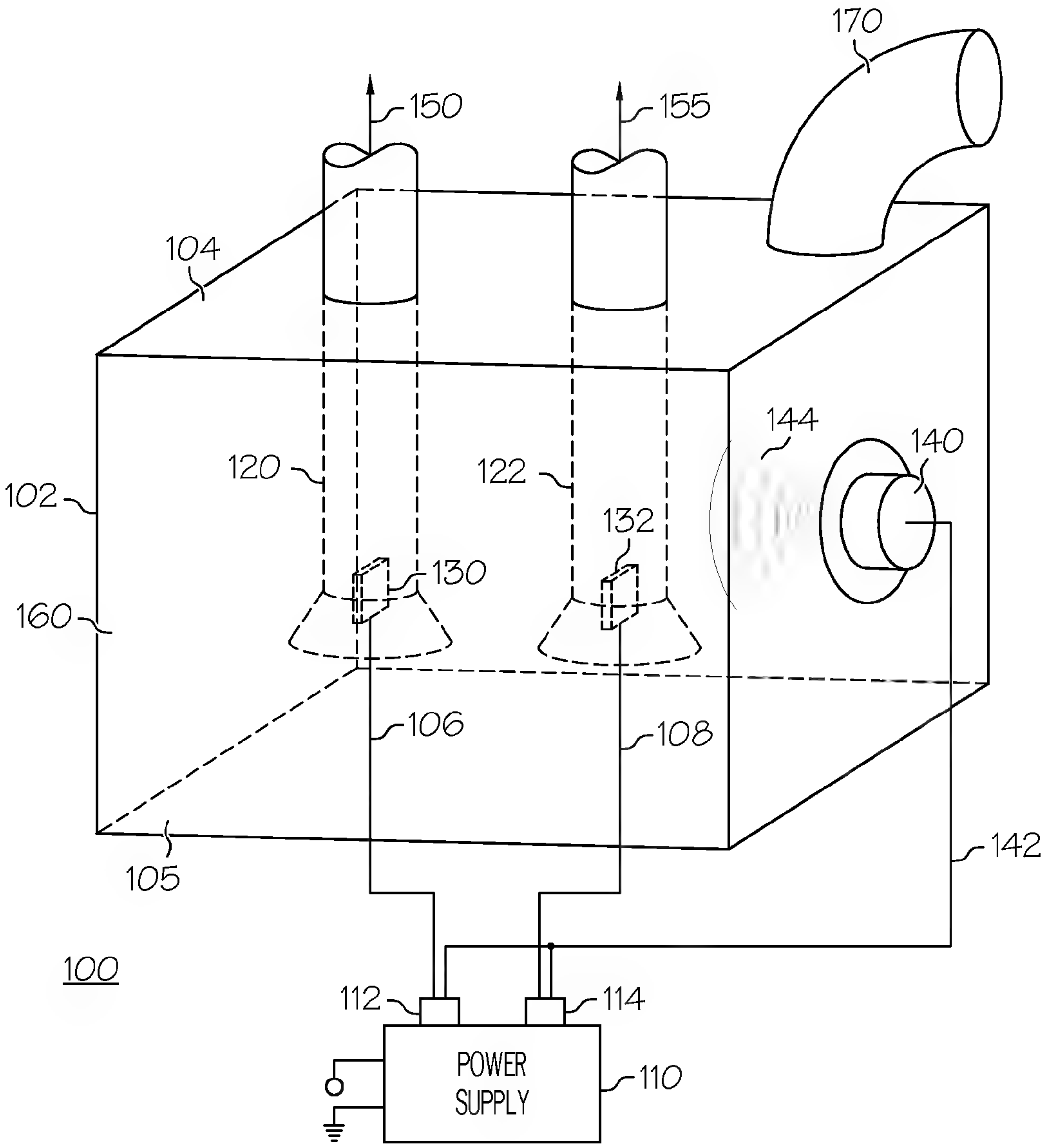
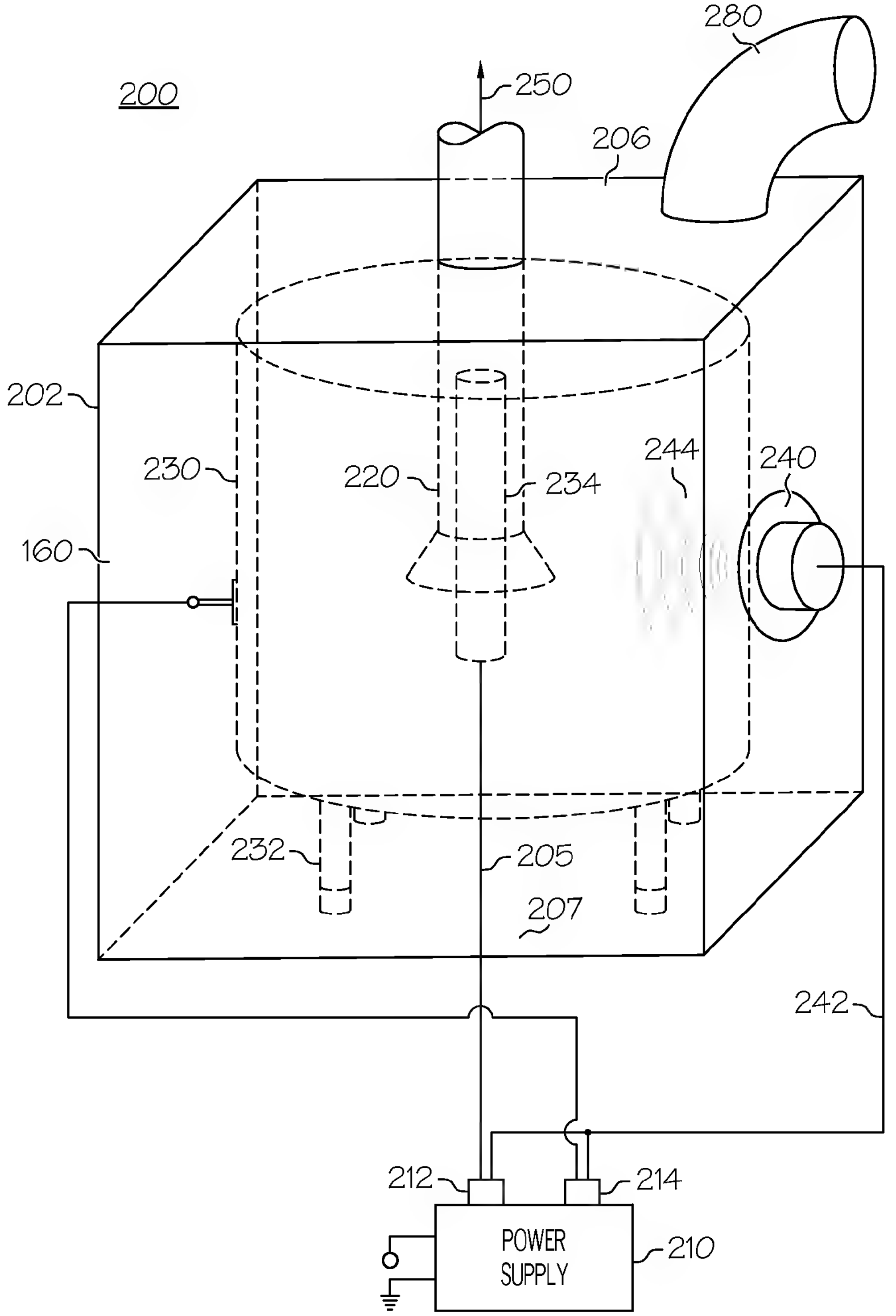

170
150
155
104
144
140
120
122
102
132
130
160
106
108
105
142
100
112
114
POWER
SUPPLY
110

FIG. 1



200
250
280
206
202
230
220
234
244
240
160
232
205
207
242
212
214
POWER SUPPLY
210

FIG. 2

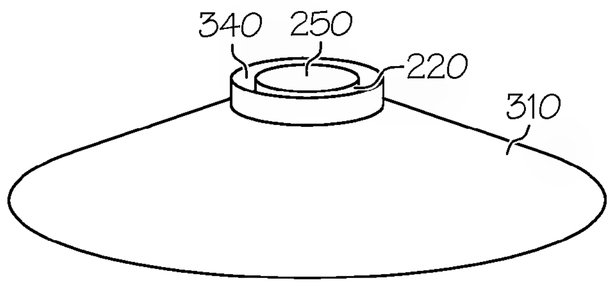

340
250
220
310

FIG. 3

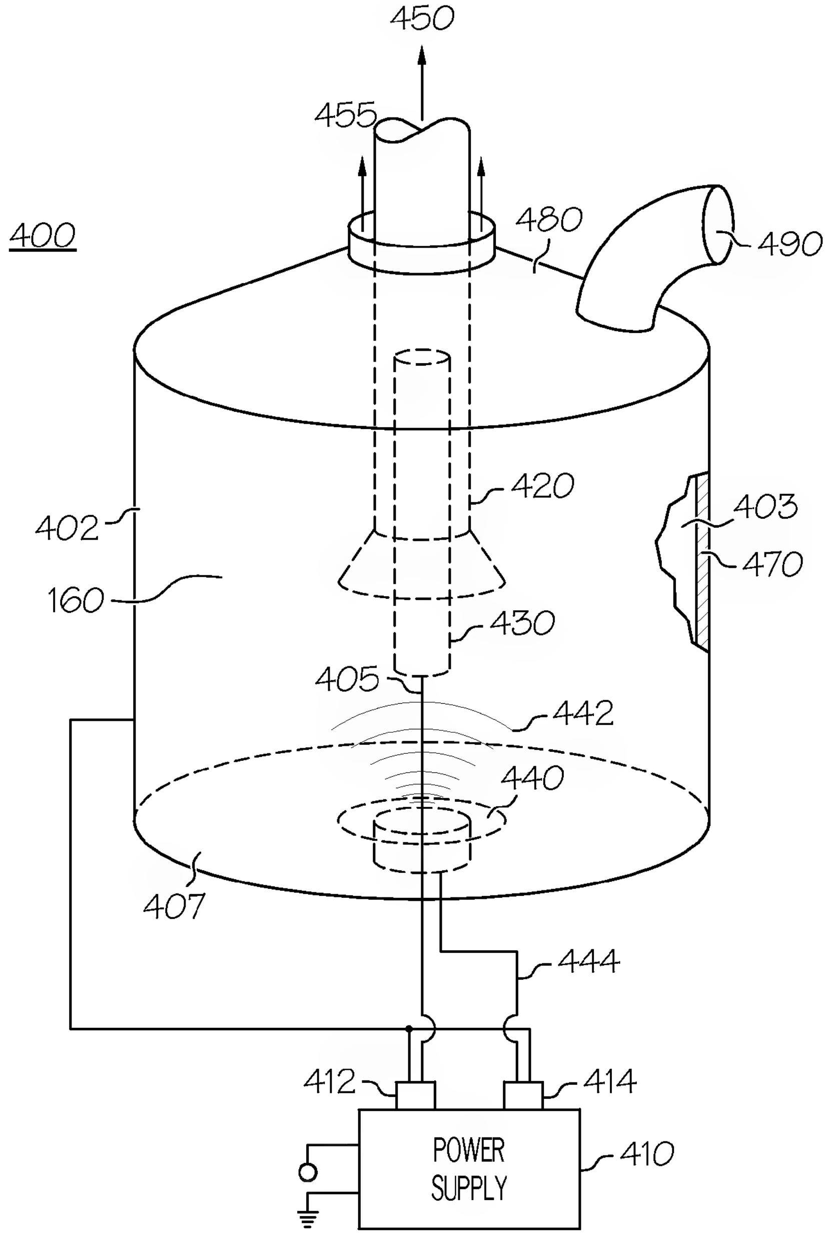

450
455
400
480
490
420
402
403
470
160
430
405
442
440
407
444
412
414
POWER SUPPLY
410

FIG. 4

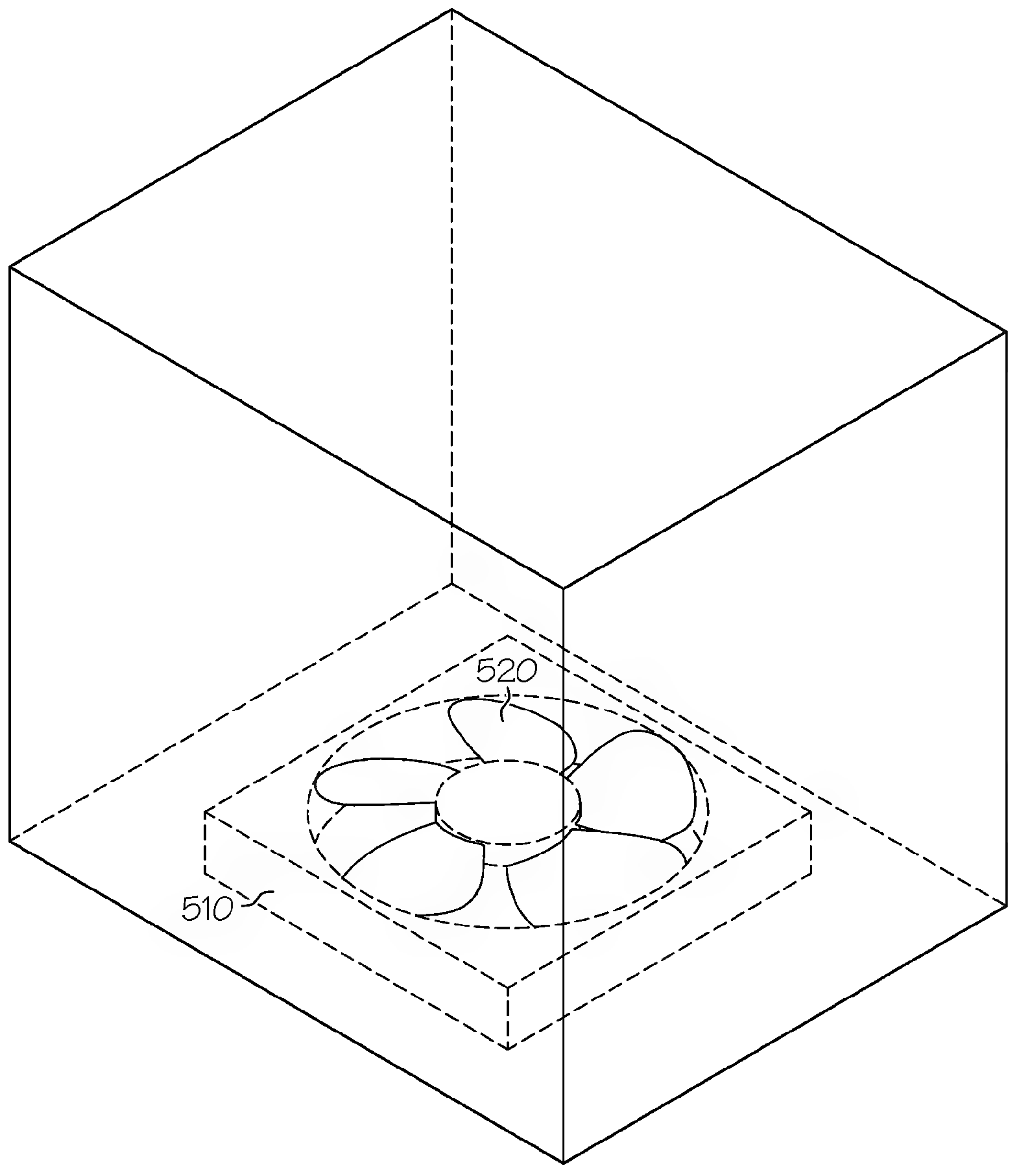


FIG. 5

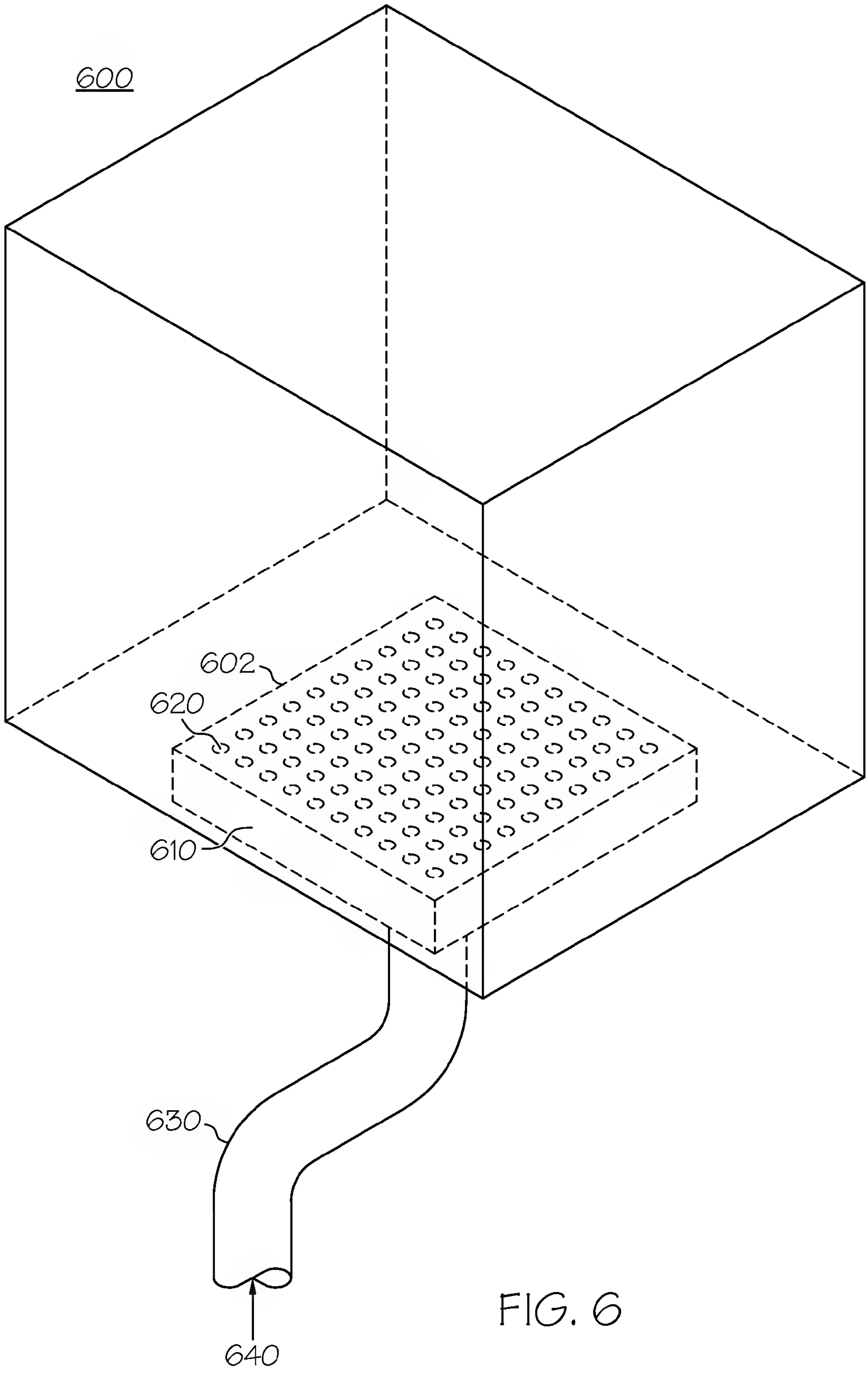
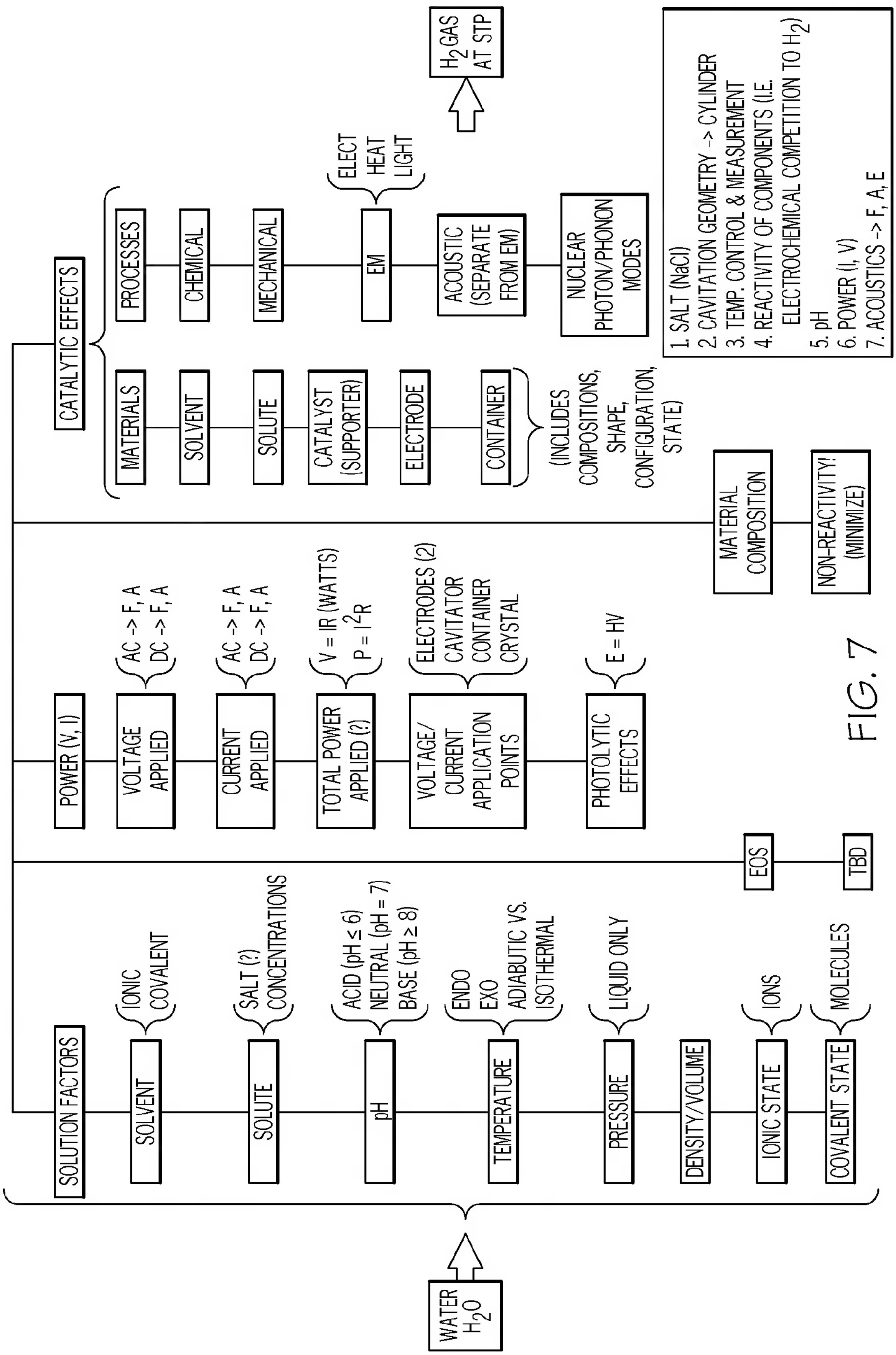


FIG. 6



WATER H_2O
SOLUTION FACTORS
SOLVENT
IONIC
COVALENT
SOLUTE
SALT (?)
CONCENTRATIONS
pH
ACID (pH ≤ 6)
NEUTRAL (pH = 7)
BASE (pH ≥ 8)
TEMPERATURE
ENDO
EXO
ADIABUTIC VS.
ISOTHERMAL
PRESSURE
LIQUID ONLY
DENSITY/VOLUME
IONIC STATE
IONS
COVALENT STATE
MOLECULES
EOS
TBD
POWER (V, I)
VOLTAGE APPLIED
AC -> F, A
DC -> F, A
CURRENT APPLIED
AC -> F, A
DC -> F, A
TOTAL POWER APPLIED (?)
V = IR (WATTS)
$P = I^2R$
VOLTAGE/ CURRENT APPLICATION POINTS
ELECTRODES (2)
CAVITATOR
CONTAINER
CRYSTAL
PHOTOLYTIC EFFECTS
E = HV
MATERIAL COMPOSITION
NON-REACTIVITY! (MINIMIZE)
CATALYTIC EFFECTS
MATERIALS
SOLVENT
SOLUTE
CATALYST (SUPPORTER)
ELECTRODE
CONTAINER
(INCLUDES COMPOSITIONS, SHAPE, CONFIGURATION, STATE)
PROCESSES
CHEMICAL
MECHANICAL
EM
ELECT
HEAT
LIGHT
ACOUSTIC (SEPARATE FROM EM)
NUCLEAR PHOTON/PHONON MODES
H_2 GAS AT STP
1. SALT (NaCl)
2. CAVITATION GEOMETRY -> CYLINDER
3. TEMP. CONTROL & MEASUREMENT
4. REACTIVITY OF COMPONENTS (I.E. ELECTROCHEMICAL COMPETITION TO H_2)
5. pH
6. POWER (I, V)
7. ACOUSTICS -> F, A, E

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/049040

A. CLASSIFICATION OF SUBJECT MATTER
INV. C25B1/04 C25B15/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C25B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2005/005009 A2 (BAR GADDA LLC [US]) 20 January 2005 (2005-01-20) claims 1,14,28-33,41,42,55,64 page 19, line 28 - line 34	1-18
X	WO 2007/124443 A2 (PLESS BENJAMIN [US]) 1 November 2007 (2007-11-01) claims 1,2,5,20,22-24 paragraph [0016]	1-18
X	DE 44 28 931 A1 (EPPLE ALBRECHT [DE]) 22 February 1996 (1996-02-22) claims 1,6-8 column 2, lines 1-9,21-26,31-36 figure 1	1-18

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 October 2009	02/11/2009

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Perednis, Dainius

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/049040

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 40 25 803 A1 (SCHEUERMANN JOACHIM [DE]) 20 February 1992 (1992-02-20) claims 1-6 figure 1 column 1, line 30 - line 43	1-18
X	US 4 107 008 A (HORVATH STEPHEN) 15 August 1978 (1978-08-15) claims 1-6,9-11 column 2, paragraph 1	1-18
X	US 4 394 230 A (PUHARICH HENRY K [US]) 19 July 1983 (1983-07-19) claims 1,3,5-9	1-18
Y	DEMOZ A ET AL: "Iodide mediated electrolysis of acidic coke/coal suspension" JOURNAL OF APPLIED ELECTROCHEMISTRY, KLUWER ACADEMIC PUBLISHERS, DO, vol. 38, no. 6, 4 March 2008 (2008-03-04), pages 845-851, XP019606251 ISSN: 1572-8838 page 847, right-hand column page 848, left-hand column *Conclusions*; page 851, left-hand column	1-18
Y	US 2003/019791 A1 (AUSTIN DOUGLAS P [US]) 30 January 2003 (2003-01-30) claims 2-6 paragraphs [0030], [0031], [0035], [0044]	1-18

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2009/049040

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US 2003019791	A1	30-01-2003	WO	02102746 A1	27-12-2002